Solar power forecasting: application of the NMMB/BSC-CTM on-line chemical weather prediction model in central Europe

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Introduction

In the beginning of April 2014, Northern Europe was affected by a mineral dust intrusion. On 4 April 2014, the power prediction for German solar installations was estimated as 21GW, whereas the measured power production merely reached 11GW. This strong overestimation significantly affected the hourly price in the wholesale electricity market: prices were firstly assessed at around 27€/MWh but rapidly reached a level close to 150€/MWh after recognizing the lack of solar output.

It has been found that a large proportion of the uncertainty of existing NWP models can be attributed to the lack of accurate aerosol data used in order to model solar radiation. Despite the advancements in the modelling of aerosol-cloud interactions, current meteorological models use parametrizations made mostly for climate considerations (generally monthly-based). The NMMB/BSC Chemical Transport Model (NMMB/BSC-CTM) is a new on-line chemical weather prediction system coupling atmospheric and chemical processes. The NMMB/BSC-CTM is the operational model of the Barcelona Dust Forecast Center of the WMO (http://dust.aemet.es). Previous studies have analyzed the predictability of the NMMB/BSC-CTM to reproduce dust outbreaks and their impact in solar radiation close to source regions such as the Mediterranean area and North Africa (Gkikas et al., 2015) where mineral dust has a high impact in the solar irradiance due to direct radiative effect.

The aim of this work is to analyze the performance of the NMMB/BSC-CTM to simulate a mineral dust intrusion far from the source regions to explore the applicability for solar energy forecast purposes.

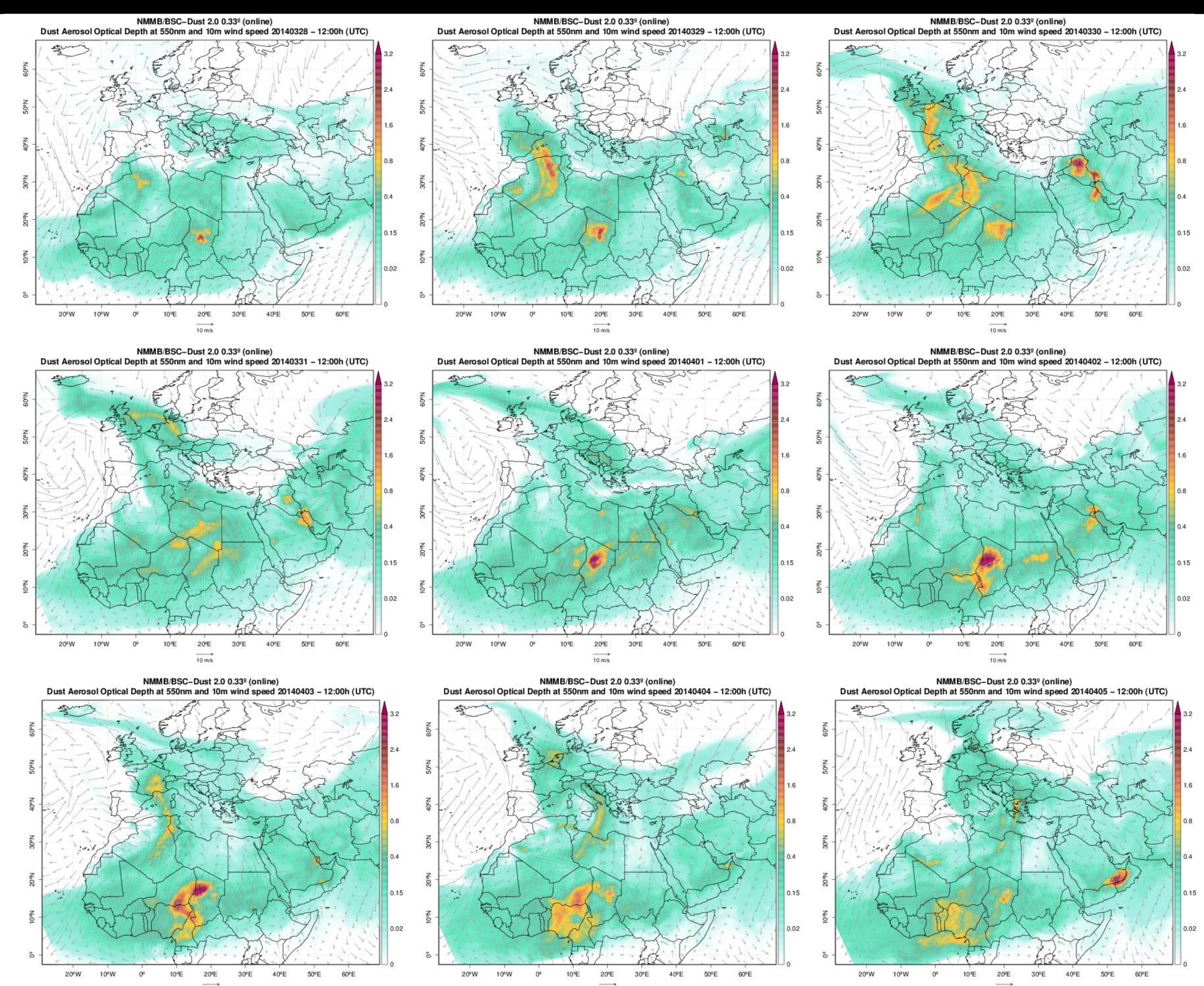

Fig. 2. Aerosol Optical Depth at 550 nm and 10m wind speed: 28 March 2014 – 5 April 2014. NMMB/BSC-CTM 0.33° (RADON)

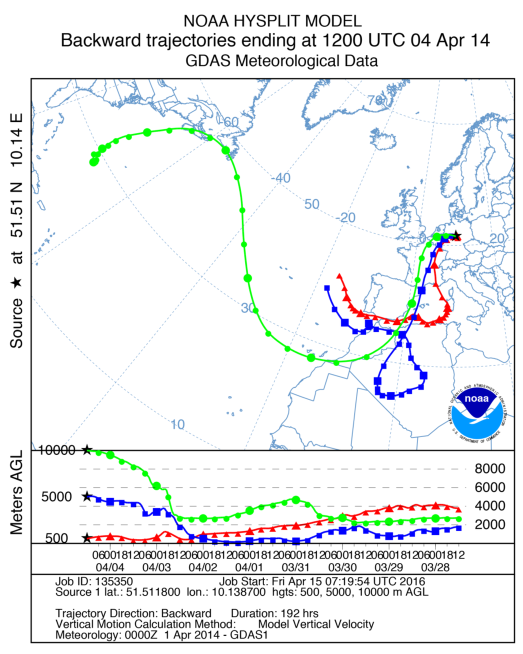

Fig. 1. Backward trajectories ending at central Europe at 0.5, 5 and 10 km computed with HYSPLIT (Stein et al., 2015; Rolph, 20016)

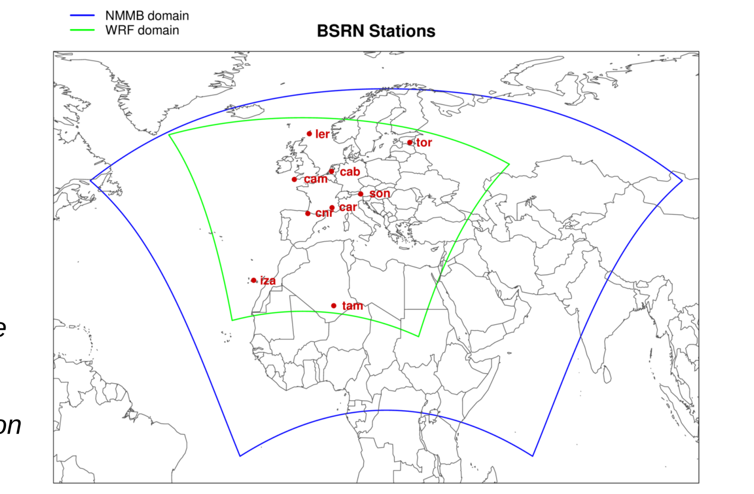

Fig. 3. Model domains and available radiation measurements from the World Radiation Monitoring Center (WRMC)- Baseline Surface Radiation Network (BSRN).

Methodology

NMMB/BSCDust model contains a dust module embedded online within the NCEP Nonhydrostatic Multiscale Model (NMMB). It provides weather and dust forecasts, from regional to global scales, thanks to its unified nonhydrostatic dynamical core. Dust cycle is represented through several parameterizations describing dust particles' sources, emissions, transport, removal from the atmosphere (wet and dry deposition) as well as the interaction with the radiation (Pérez et al., 2011).

- Simulated period (spin-up period and key event): 20 March 2014 6 April 2014
- Key event: 28 March 2014 – 6 April 2014

Table 1. Model description and main parameterizations

Model	Spatial resolution	Vertical resolution	Met. initial conditions	Dust-radiation interaction	Land use
NMMB/BSC-CTM 0.1° (off)	0.1° x 0.1°	40 up to 50hPa	GFS	RADOFF	USGS/STATSGO-FAO
NMMB/BSC-CTM 0.33° (off)	0.33° x 0.33°	24 up to 50hPa	GFS	RADOFF	USGS/STATSGO-FAO
NMMB/BSC-CTM 0.33° (on)	0.33° x 0.33°	24 up to 50hPa	GFS	RADON	USGS/STATSGO-FAO
WRF-ARW v.3.7	12x12 km	37 up to 50hPa	GFS	-	CORINE

Methodology

- The NMMB/BSC-CTM model is able to reproduce the dust event. A comprehensive evaluation of this episode and other periods of study can be found here: http://www.bsc.es/earth-sciences/mineral-dust/nmmbbsc-dust-forecast/

Including a dust module in a model's calculations:

- improves its skill for reproducing surface irradiance during heavy dust events.
- under strong dust plume maximum temperature reduction (not shown).
- a higher resolution provides a higher mineral dust concentration, especially of dust peaks.
- differences between online/offline dust integration inside the model are moderate due to the relatively low dust concentrations in central Europe.

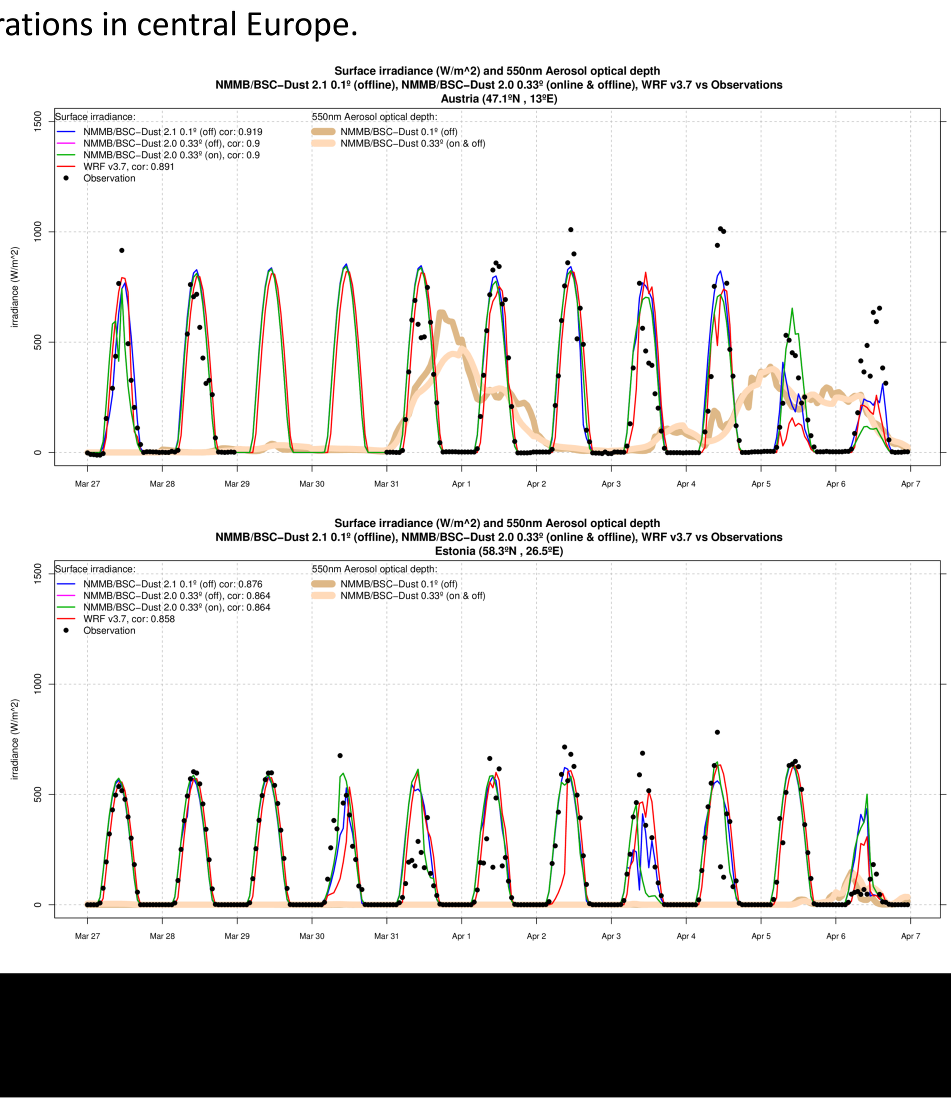

Fig. 4. SW radiation at the ground evaluated against BSRN measurements (left-hand axis). AOD (right-hand axis). Austria (son) (top-panel); Estonia (tor) (bottom-panel).

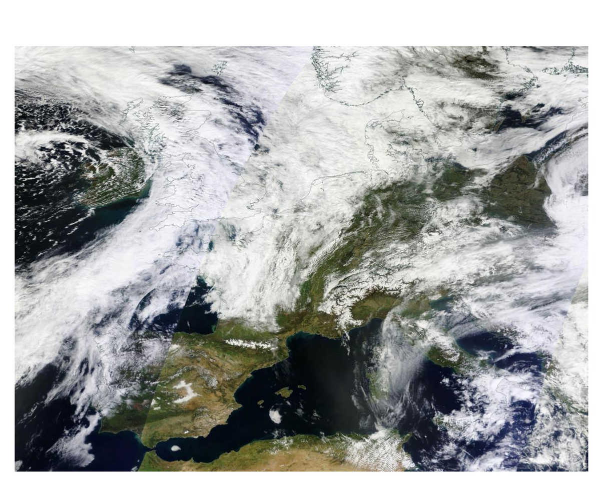

Fig. 5. MODIS-Terra. Corrected reflectance, true color. 2014-04-04-10:40h

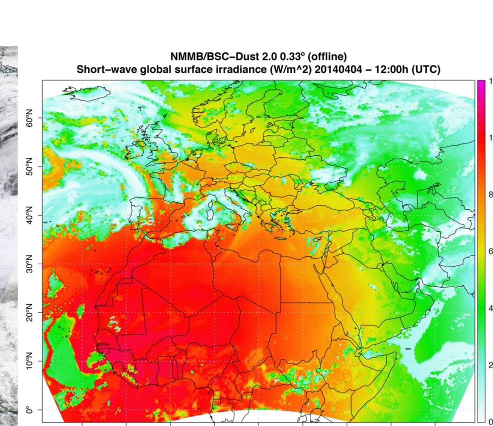

Fig. 7. SW radiation at the ground. 2014-04-04-12:00h

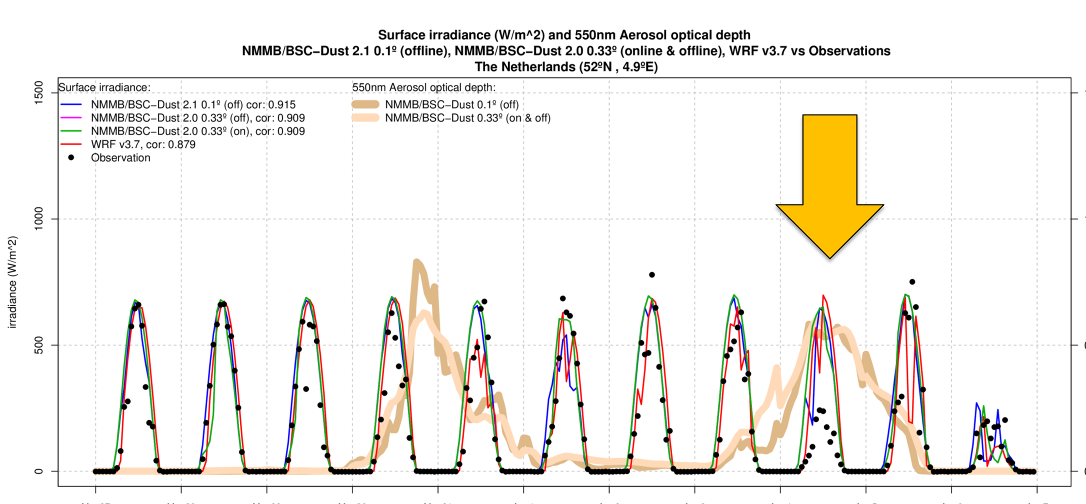

Fig. 9. SW radiation at the ground evaluated against BSRN measurements (left-hand axis) in The Netherlands (cab station). AOD (right-hand axis).

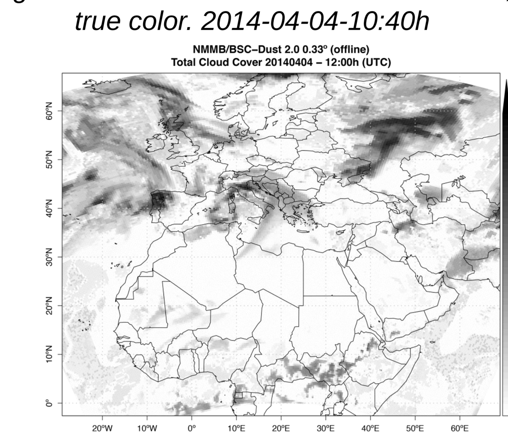

Fig. 6. Cloud cover. 2014-04-04-12:00h

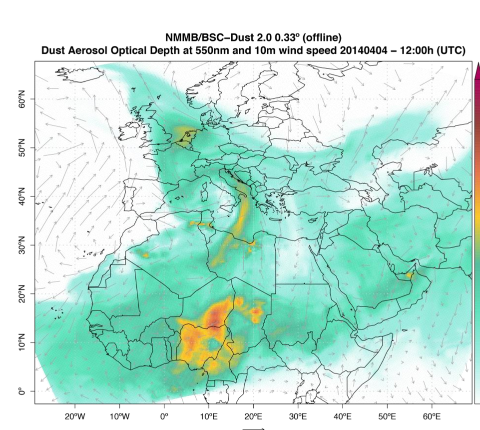

Fig. 8. AOD at 550nm. 2014-04-04-12:00h

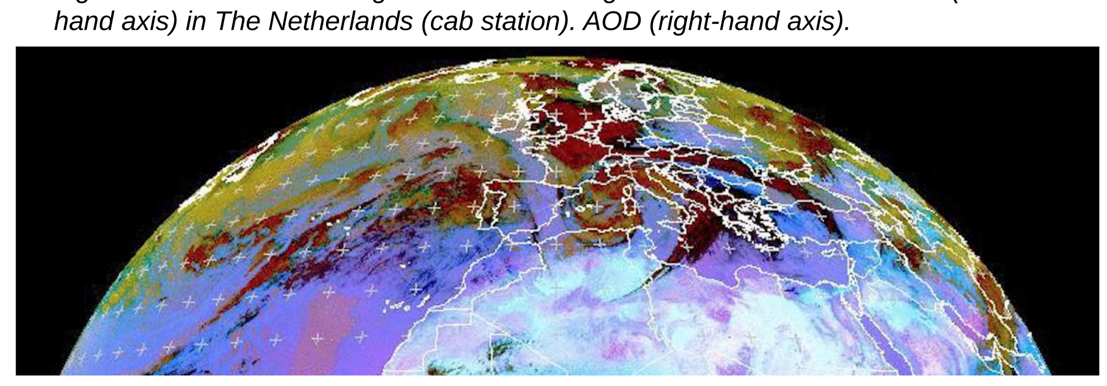

Fig. 10. EUMETSAT MSG RGB. Dust appears pink or magenta. Dry land looks from pale blue (daytime) to pale green (nighttime). Thick, high-level clouds have red-brown tones and thin high-level clouds appear very dark.

Ice-nucleation, cloud formation.
On 4 April 4th 2014, clouds covered central Europe (Fig. 5) however NWP models didn't predict such amount of clouds (Fig. 6) implying a significant overestimation of incoming radiation (Fig. 7).
NMMB/BSC-CTM model properly reproduced the dust event (Fig. 8), however the model didn't find any significant impact upon the incoming SW (Fig. 9).
Fig. 10 shows that the clouds observed in Fig. 5 are thin high-level clouds. The presence of mineral dust at high altitude during this period can suggest the formation of clouds due to the presence of mineral dust (ice-nucleation implementation; on-going work).

Conclusions

The highest priority for energy network operators is the balance between energy demand and supply. Before the introduction of renewable energies, demand was matched with base-load power plants (coal and nuclear) and generating plants that can be scheduled, usually hydroelectric and fossil-based peak load power plants. This landscape has been changing rapidly with the integration of renewable energies into the energy mix over recent years.

Solar power forecasting prevents energy loss and improves the management of solar plants. In general terms, current NWP models don't use online predicted mineral aerosol concentration for radiation calculations. Central Europe is periodically affected by mineral dust intrusions, mainly in spring. Under these conditions, it is crucial to accurately model aerosol-cloud interactions.

The NMMB/BSC-CTM has proved to be a useful tool to predict mineral dust outbreaks:

- significant reduction of incoming SW under strong dust plumes.
- minor reductions for moderate events like the ones affecting central Europe.

On-going work

- Perform a climatological assessment to identify a statistically representative group of mineral dust episodes affecting central Europe to: 1) Analyze their impact on solar power generation; 2) Identify major weather events; 3) Analyze aerosol-cloud formation.; 4) Deposition
- Implementation and evaluation of indirect radiative effects.
- Integration of anthropogenic emission sources.

References and acknowledgment:

- *Gkikas et al. (2015): Atmospheric circulation evolution related to desertdust episodes over the Mediterranean. Q.J.R. Meteorol. Soc.*
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